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Estimation of Low Frequency Scattering from Fish Schools on the Continental Shelf off New Jersey

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14. ABSTRACT

The GeoClutter 2001 (GC01) experiment conducted on the continental shelf of New Jersey in April and May 2001 focused on physical mechanisms causing geologically produced acoustic clutter and false targets around 400 Hz. During GC01, a large, strong unidentified target was detected. In May 2001, backscatter measurements from the ocean volume were made in the same area at 2 to 10 kHz and at 38 kHz to examine scattering from fish during the Boundary Characterization (BC01) experiment. Also, the National Marine Fisheries Service (NMFS) conducted a trawl and 38 kHz echosounder fisheries survey in the region from February to April 2001. Data from BC01 and NMFS show that large demersal and pelagic fish schools occur on the New Jersey shelf in spring. Demersal schools are most likely composed of scup, seabass, hake, or dogfish shark. Pelagic schools are probably composed of herring-like fish or butterfish. Results of modeling backscatter from these species indicate that these schools could produce significant scattering at 400 Hz and could have easily produced the large unidentified target observed during GC01.

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Fish schools; Volume scatter; Clutter; False targets

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Introduction

During the spring of 2001, two related experiments took place on the outer continental shelf of New Jersey in an area roughly bounded by 39°31'N, 72°42'W; 39°18'N, 72°22'W; 38°53'N, 72°52'W; and 39°04'N, 73°14'W (Figure 1). The GeoClutter 2001 (GC01) experiment was conducted from 27 April to 5 May and the Boundary Characterization 2001 (BC01) experiment was conducted from 10 to 20 May (Hines, et al., 2001).

GC01 was designed to identify primary physical mechanisms that cause bottom-related clutter and false targets and to aid in the development of methodology for identifying and classifying clutter and false targets in littoral waters (Anon., 2001) Acoustic frequencies employed during GC01 centered around 400 Hz. Analysis of GC01 data has shown that both surface and subsurface bottom features can produce significant clutter and false targets at 400 Hz.

During a short period of GC01, a 1 km by 4 km patch of scattering of unknown origin was observed over a bottom depth of 80 m just southwest of the nominal experiment area. No geophysical feature, either on or near the sea floor or in deep sediments, was found that could have caused the observed scattering (Makris, et al., 2002). One possibility was that the scattering patch, referred to as Target A, may have been a large school of fish.

BC01 was designed to measure environmental parameters that control diffuse reverberation and to statistically characterize the effects of the seafloor and sea surface on broadband scattering and propagation at frequencies from less than 1 kHz to 10 kHz (Hines, et al., 2001). Because it has been shown that concentrations of fish can contaminate measurements of surface and bottom scatter (Gauss, et al., 2002), the Naval Research Laboratory (NRL) conducted a series of measurements aboard *R/V ENDEAVOR* to determine the likelihood of significant fish scattering during BC01. A comprehensive 38 kHz fisheries echosounder survey of the experiment area was conducted and, at several sites, additional measurements were made at 2 to 10 kHz with NRL's mid frequency fisheries sonar (MFFS). Demersal and pelagic fish schools were detected, but no schools of the size of Target A were found (Nero, et al., 2001). However, the NRL survey did not extend southwest of the experiment area to the location where Target A was detected. To determine if a large school of fish causing significant scattering at 400 Hz could be possible, a more thorough examination has been conducted of available fish information for the New Jersey shelf.

In this report, several unresolved issues of fish scattering are given further consideration. First, an effort is made to better determine the composition of many of the fish schools that were observed during the NRL survey. Second, National Marine Fisheries Service (NMFS) data sets are examined to determine if a large demersal or pelagic fish school could have occurred just southwest of the experiment area. Third, assuming such a large school could occur, acoustic modeling was employed to determine if the potential species could produce a strong scattering response at 400 Hz.
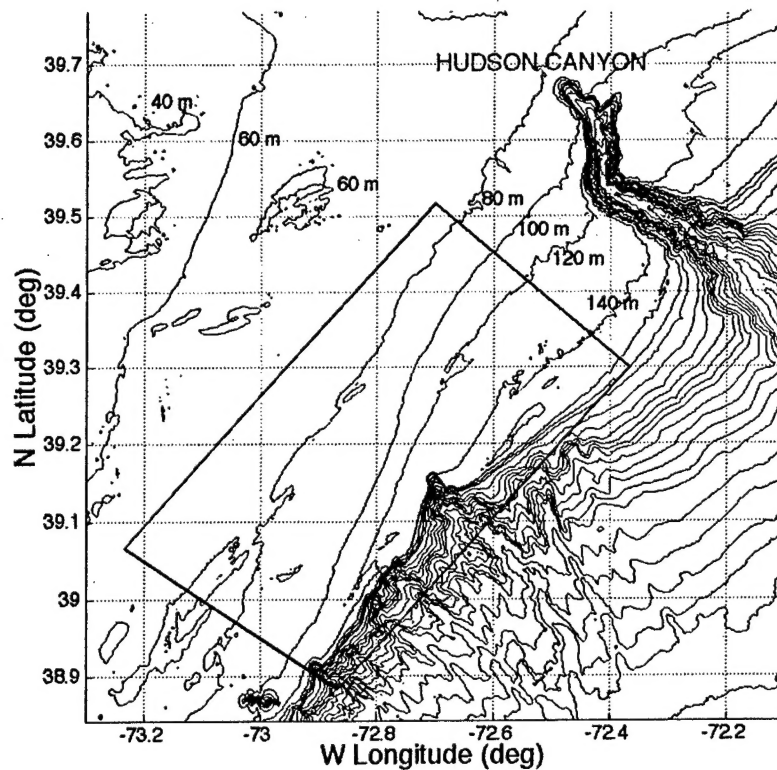
Figure 1. Location of the GC01/BC01 experiment area (polygon) on the outer continental shelf of New Jersey.

NMFS Trawl Data

The National Oceanic and Atmospheric Administration (NOAA) Ship *ALBATROSS IV* conducted a research cruise from 27 February to 30 April, 2001 that covered most of the shelf region from Cape Hatteras to Georges Bank. Both 38 kHz echosounder and fisheries trawl catch data were obtained.

Figure 2 shows the location of 37 trawls taken in the general vicinity of the GC01/BC01 experiment area, between 37.5°N and 40°N. These trawls occurred during three periods: 28 February to 2 March, 27 trawls; 17 to 19 March, 9 trawls; and 28 March, 1 trawl. The trawl catches indicate that several species on the continental shelf of New Jersey in March are concentrated between 70 and 130 m. Although there is an apparent depth dependent distribution of species, there is no discernable geographic trend in occurrence of fish in relation to the 30 day period over which the trawls occurred.

Information was collated on all abundant fish in the trawl catches, including both swimbladdered and non-swimbladdered fish. Abundance was measured as the total weight in kilograms of a species caught in a trawl. Abundant swimbladdered species (with median lengths) included silver hake (29 cm), red hake (34 cm), spotted hake (23 cm), Atlantic herring (26 cm), alewife (26 cm), American shad (30 cm), scup (17 cm) and

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black seabass (24 cm). Non-swimbladdered species included dogfish shark (70 cm), Atlantic mackerel (27 cm), and butterfish (11 cm).
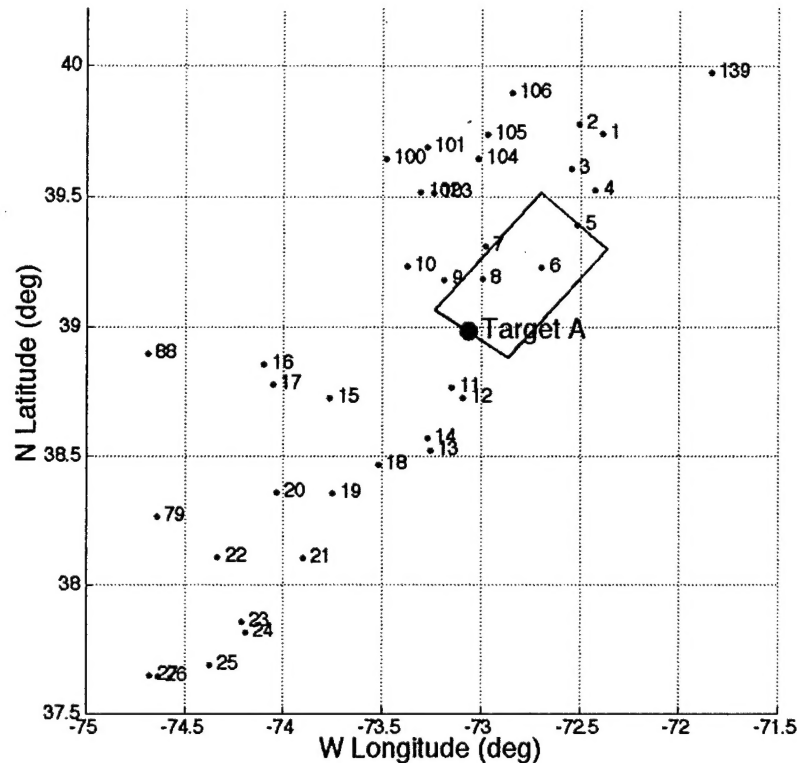

Figure 2. Location of the NMFS research trawls (numbered) in relation to the GC01/BC01 experiment area (polygon).

Demersal species include the hakes, seabass, scup, and dogfish. Pelagic species include herrings-like fishes (Atlantic herring, alewife, and shad), butterfish and mackerel. Catch locations and abundances for demersal and pelagic species are given in Figures 3 and 4, respectively. The hakes as well as the herrings have been grouped in these figures. The NMFS trawls were essentially bottom trawls that caught pelagic fish during the trawl's descent to the sea floor and ascent to the surface. Thus, abundances of demersal species can be compared as can those of pelagic species, but abundances of demersal species can not be compared to abundances of pelagic species.

In a pre-BC01 assessment of potential fish scatterers and in the initial NRL report on BC01 (Nero et al., 2001), only swimbladdered species (hakes, black seabass and scup) were considered as potential demersal scatterers. The NMFS trawl catches confirm that these species were in the experiment area. However, the trawls also show that dogfish were very abundant, comprising over 90% of the demersal fish catch. Therefore, dogfish could have been potentially important scatterers, their large numbers compensating for weak scattering from an individual. Dogfish were more abundant to the south of the

experiment area but were also fairly abundant at several locations within the area (Figure 3).
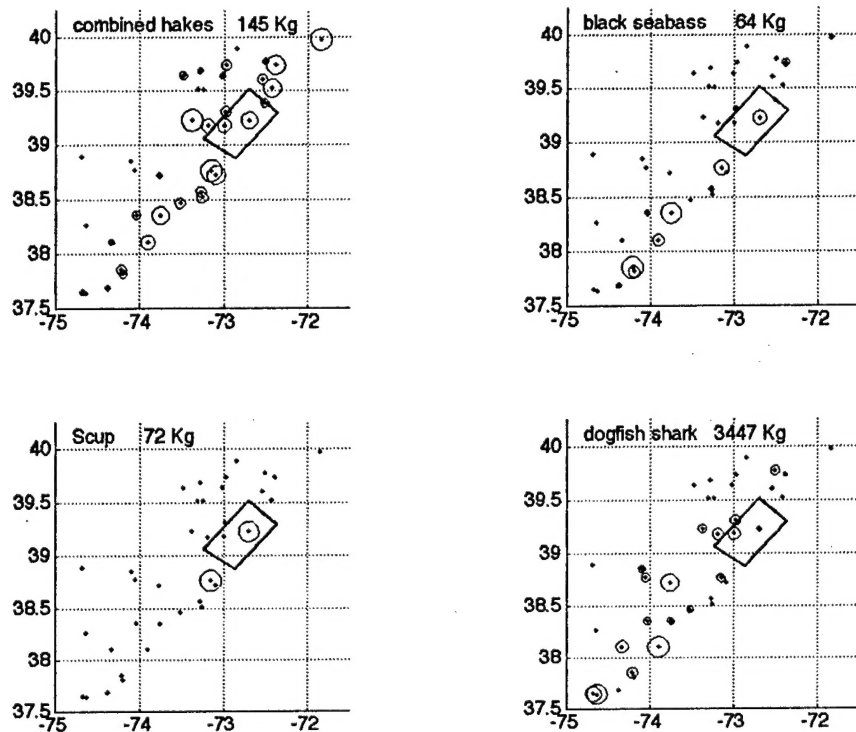

Figure 3. Catch of demersal fish from a NMFS trawl survey of the outer continental shelf off New Jersey in February to March 2001. Each panel shows the total catch with circle size proportional to catch weight. Polygon corresponds to the GC01/BC01 experiment area shown in Figures 1 and 2.

Atlantic mackerel comprised 75% of the pelagic catch, but they were significantly shallower than the GC01/BC01 experiment area and are not considered further (Figure 4). Herrings were twice as abundant as butterfish. Herrings were found within the experiment area, but were more abundant in shallower water inshore and north of the area (Figure 4). This agrees with the general trend found in the NRL echosounder survey, where greater numbers of pelagic schools were seen in the northern portion of the experiment area (Nero et al., 2001).
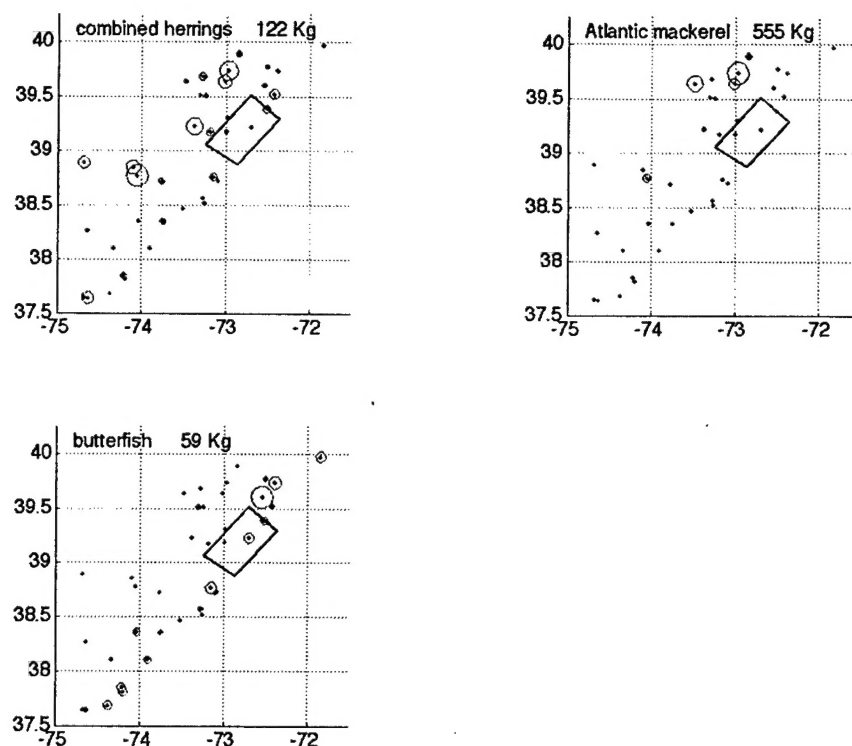
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Figure 4. Trawl catch data for pelagic species. Symbols as in Figure 3.

NMFS Echosounder Data

Figure 5 shows the portion of the *ALBATROSS IV* echosounder track from 28 February through 2 March, which passed through the GC01/BC01 experiment area. The echosounders installed on the *ALBATROSS IV* and *R/V ENDEAVOR* were identical, both Simrad Model EK500. During the NMFS trawl survey (*ALBATROSS IV*), the echosounder was run continuously during transit between trawl locations and during the trawl tows. Several large concentrations of fish were observed near the shelf edge. One especially large school, roughly 2 x 10 km in extent, was found about 10 nmi southwest of the GC01/BC01 experiment area (Figure 5). Most of the schools observed during the NMFS survey were near the 100 m contour. During the NRL survey about 6 weeks later, schools had moved shoreward to around the 80 m contour, suggesting the fish were slowly moving across the shelf toward shore during the spring (Nero, et al., 2001). In addition, many of the schools of fish observed by NMFS were to the southwest of the GC01/BC01 experiment area and they appeared larger and denser than those observed later by NRL within the experiment area. Further evidence that large scale biological changes were taking place over this 6 week interval was the presence of large pelagic schools of squid in the NMFS survey which were not present during the NRL survey.

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Although not significant as acoustic targets, the movement of the squid is indicative of shelf-wide faunal changes during this period.
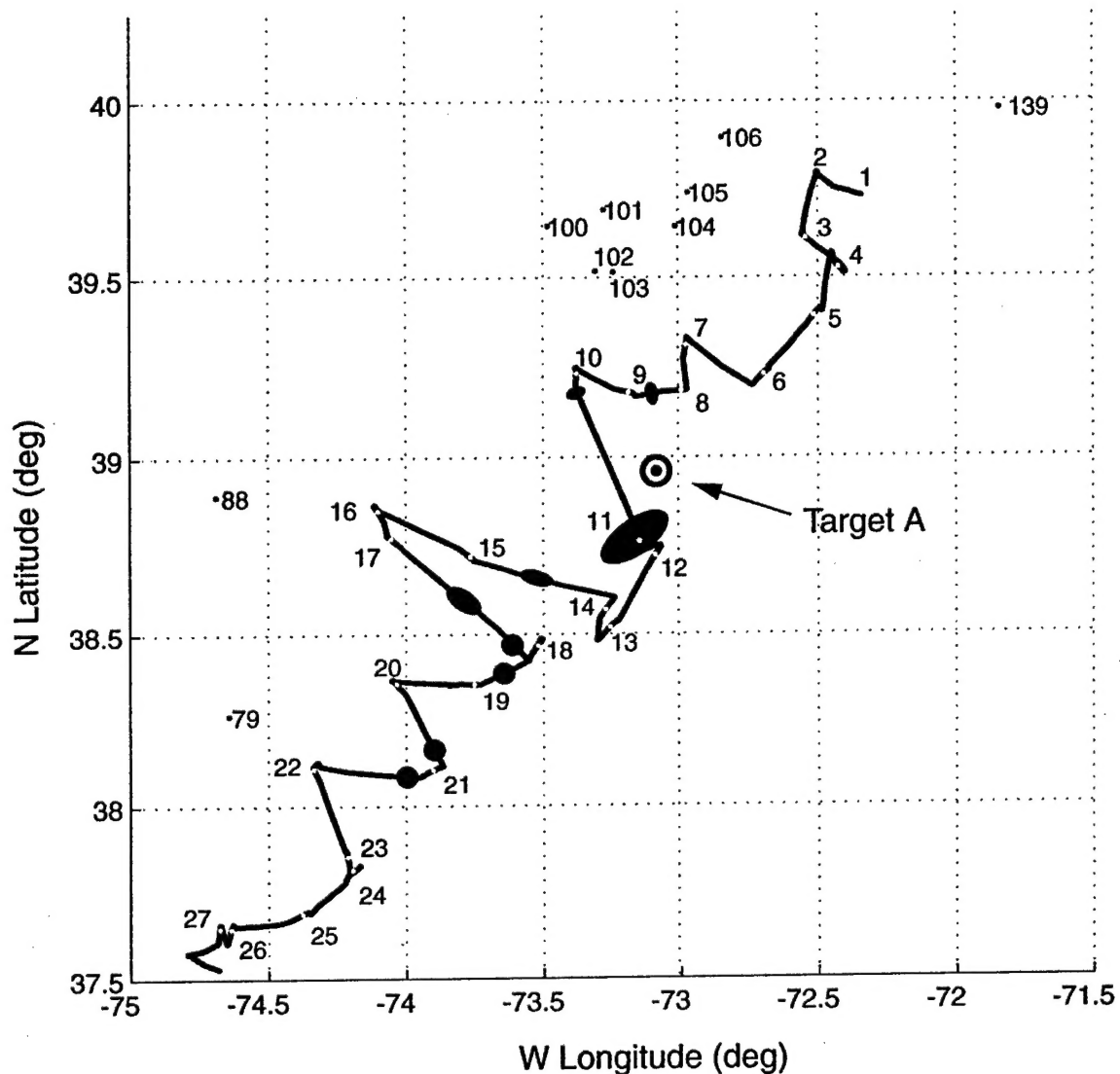

Figure 5. NMFS trawl stations and acoustic survey track of the NOAA Ship *ALBATROSS IV*, from 28 February to 2 March. The approximate locations where the echosounder record indicated large fish schools are shown as black ellipses along the vessel track.

Of the 37 trawls examined, 13 occurred at bottom depths between 70 to 130 m and are considered especially relevant. Of these 13 tows, echosounder data indicate that nine occurred near the edge of large fish concentrations. Trawl 11 occurred inside a very large school (Figure 5). The catch in Trawl 11 was primarily dogfish, with scup and some hake, suggesting that large schools of fish observed on the New Jersey shelf were a mixture of several species.

Thus, both trawl and echosounder data from the *ALBATROSS IV* survey provide reasonable evidence that a large concentration of fish could have been present at the location of Target A during the GC01 experiment.

Fish Scattering Modeling

To examine scattering from demersal fish schools at 400 Hz, scattering models were used to extrapolate MFFS backscatter data collected at 2 to 10 kHz down to 100 Hz. A backscattering curve was generated for each of the most common species. Curves for each species were adjusted to account for the differences in relative abundances of the six most common demersal species in the 13 trawls taken between 70 and 130 m. These curves were summed to obtain an overall total scattering curve. For five of the six demersal species with swimbladders, the NRL swimbladder scattering model (Love, 1978) was used. All have closed swimbladders which, for modeling purposes, were assumed to be the bladder volume required to provide neutral buoyancy. For the dogfish shark, the one non-swimbladdered demersal species, a model of scattering from a bent cylinder was used to calculate the scattering from the fish body (Stanton, 1989). All fish were assumed to be between 60 and 90 m deep, a depth range encompassing the general depth range of Target A. Modeled scattering from demersal species is shown in Figure 6. The total scattering curve represents the sum for all species with the level set by "eye" to fit measurements that were obtained by dipping the MFFS source and receiver near a layer of fish within a large demersal school found at 60 to 80 m deep during BC01 (Nero, et al., 2001).

For non-swimbladdered fish, the general rule-of-thumb is that a roll-off from geometric to Rayleigh scattering will occur at body length to wavelength ratios of about 0.7; at about 1.5 kHz for dogfish (Love, 1971). Contrary to what was stated in the initial BC01 report (Nero, et al., 2001), this means that strong scattering from numerous dogfish could have occurred at 2 to 10 kHz during the MFFS measurements. This possibility could create confusion in interpreting the MFFS data and in determining whether scattering at low frequencies was from swimbladdered or non-swimbladdered fish. However, Figure 6 confirms that, although dogfish might be significant scatterers above about 2 kHz and could confuse interpretation of mid frequency results, they contribute little below 2 kHz. The primary scatterers contributing to the main resonance peak around 1 kHz are scup, black sea bass, and hake. These fish also produce substantial backscatter at 400 Hz. Based on these model results, scattering levels at 400 Hz, are expected to be only about 6 dB below those measured at 2 to 10 kHz, indicating that appreciable backscatter at 400 Hz could be produced by some of the large demersal schools.

Modeling of scattering from pelagic fish was also conducted. The swimbladder scattering model (Love, 1978) was used for the herring-like fish. Herrings have open swimbladders that compress with depth. For modeling purposes, herring swimbladders were assumed to provide neutral buoyancy at 40 m and compress according to Boyle's Law below that depth (Nero et al. 2004). The bent cylinder model (Stanton, 1989) was used for butterfish. For butterfish, the Rayleigh scattering roll-off begins at about 10 kHz. All fish were assumed to be between 70 and 100 m deep. The daytime depth range of the pelagic schools is deeper than that of the demersal schools because pelagic schools were generally in deeper water than the demersal schools. Curves were generated for each
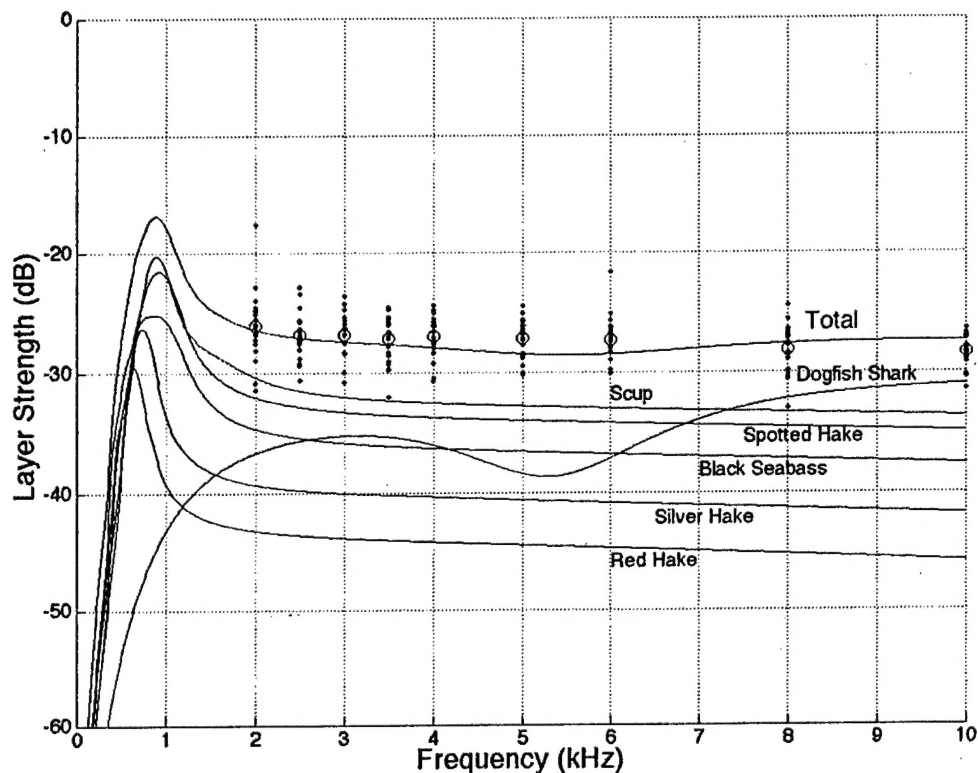
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Figure 6. Model estimates of the backscatter expected from large schools composed of a mixed assemblage of demersal fish as observed in NMFS bottom trawl survey of the New Jersey shelf during February to March 2001. The model estimate of relative backscatter from all species combined was adjusted so that the total scatter would best fit the NRL measurements (shown as data points) obtained on the night of May 18.

pelagic species and summed as they were for demersal species. Since there were no MFFS data for pelagic schools, the total curve was adjusted so that at high frequencies, it was about the same level as that for demersal species.

Model results for pelagic species are shown in Figure 7. Atlantic herring cause the primary scattering peak near 1 kHz and American shad cause the secondary peak around 700 Hz. Butterfish are very weak scatterers below 2 kHz and do not contribute to overall scattering at any frequency below 10 kHz. These results indicate that significant backscatter at 400 Hz could be produced by large pelagic schools of herring-like fish.
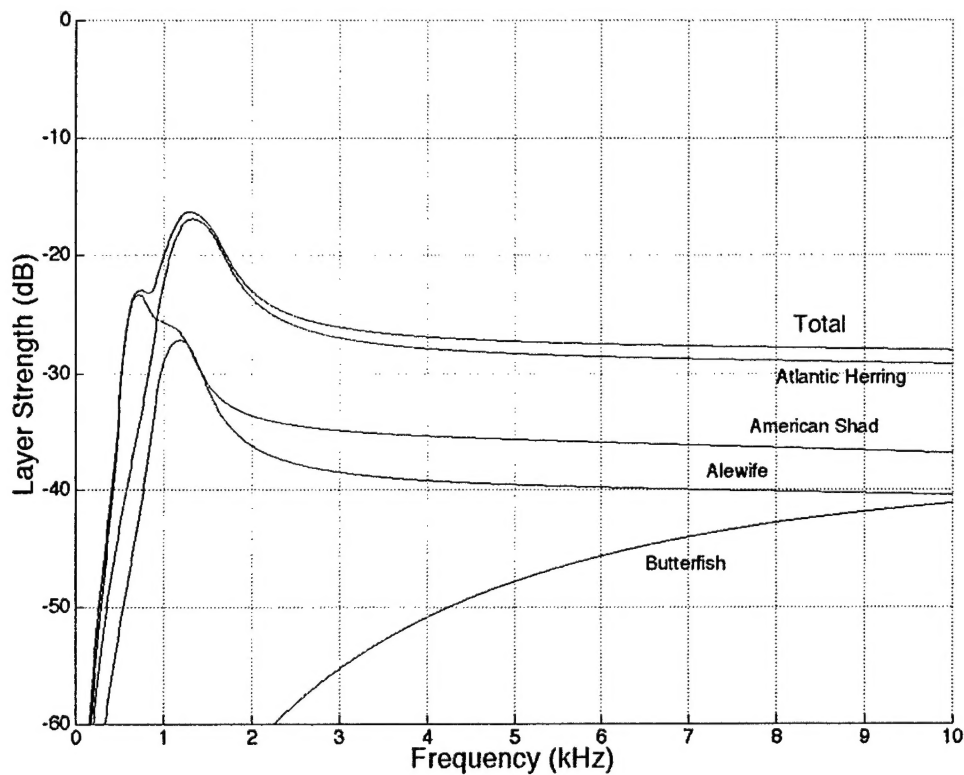
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Figure 7. Model estimates of the backscatter expected from large schools composed of a mixed assemblage of pelagic fish as observed in NMFS bottom trawl survey of the New Jersey shelf during February to March 2001. Model estimates of relative backscatter for each species was adjusted such that the total scatter would match that shown in Figure 6.

Conclusion

A re-examination of NRL acoustic results and data obtained from a fishery acoustic and trawl survey conducted by NMFS indicates that large schools of demersal and pelagic fish occurred on the New Jersey shelf in spring 2001. Demersal schools were most likely composed of a mixture of species, including scup, hake, seabass, or dogfish shark. Pelagic schools were most likely composed of herring-like fish or butterfish. Extrapolation of higher frequency backscatter measurements using theoretical models of scattering from swimbladdered and non-swimbladdered fish indicates that, because several species of large bodied fish with swimbladders were likely to be present, the schools could have produced significant scattering at 400 Hz. Hence, the large unidentified target observed during GC01 could have easily been produced by a school of swimbladdered fish.

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